GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6531

Permafrost Science at ESS:

A Workshop on GSC/CCRS Scientific Opportunities

S. A. Wolfe (Editor)

2010

Natural Resources Canada Ressources naturelles Canada

GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6531

Permafrost Science at ESS: A Workshop on GSC/CCRS Scientific Opportunities

S.A. Wolfe (Editor)

2010

This publication is available from the Geological Survey of Canada Bookstore
(http://gsc.nrcan.gc.ca/bookstore_e.php).
It can also be downloaded free of charge from GeoPub
(http://geopub.rncan.gc.ca/).

S.A. Wolfe (Editor) 2010. Permafrost Science at ESS: a Workshop on GSC/CCSR Scientific Opportunities; Geological Survey of Canada, Open File 6531, 1 CD-ROM.

Open files are products that have not gone through the GSC formal publication process.

Executive Summary:

Andy Rencz, Program Manager, Climate Change Geoscience

The permafrost region occupies approximately half of Canada’s land mass. Knowledge of the distribution of permafrost and its physical properties is critical for understanding terrain stability in Arctic environments and is required information for any sort of infrastructure development (community, transportation or natural resource sector). This knowledge is becoming increasingly important as climate changes, since the distribution and characteristics of permafrost are highly correlated with climatic conditions.

The Earth Science Sector (ESS) provides Canada with multi-disciplinary permafrost expertise. Researchers at Canada Centre for Remote Sensing (CCRS) apply information and data from a range of satellites to assist in mapping and better understanding permafrost environments as well as conducting change-detection studies. Researchers at the Geological Survey of Canada (GSC) employ a variety of field-based and thermal monitoring techniques to characterize permafrost and better understand terrain processes that may result under a changing climate. Both groups utilize various numerical modelling techniques to explain observed phenomena and to predict future conditions.

This workshop on Permafrost Science was convened to highlight the various types of permafrost expertise in ESS. In addition, this workshop identified gaps and possible opportunities for new collaborative permafrost research.

Table of Contents

Objectives and Outputs

The purpose of this half-day workshop was to provide a forum for presenting and discussing the range of permafrost scientific expertise/activities within the Earth Sciences Sector (ESS) of Natural Resources Canada. The primary output from the workshop is this report, which outlines the status of current scientific activities and lists gaps and recommendations for enhancing the research. The primary outcome of this meeting was to identify research gaps in research, and new collaborative opportunities for permafrost research within ESS (between the GSC and CCRS). The intent is to begin the development of a new research vision to be implemented in a new climate change science program starting in April 2011.

Permafrost research at GSC-CCRS – Ottawa

The Permafrost Section of the GSC-Northern Division comprises one of the few permafrost research groups in Canada. This group focuses on characterizing the northern landmass, including its thermal and physical characteristics. In general, this involves detecting and assessing the response of the permafrost environment to ongoing natural and human-induced changes; developing predictive tools for anticipating changes to permafrost under climate warming or other disturbances; and understanding the role of permafrost in controlling hazards also found in temperate Canada, such as landslides, ground subsidence, and contaminant transport.

CCRS is the Canadian Government's centre of excellence for remote sensing and geodesy, and works to ensure that satellite data serves the information needs of all Canadians. Within CCRS a number of scientists work on satellite data applied to Canada's North, and some specifically on remote sensing capabilities to monitor and model permafrost terrain. These scientists use both multi-spectral satellite data to monitor surface and vegetation characteristics, and radar data to detect ground movement.

Workshop and Presentation Structure

The workshop approach involved a series of brief scientific presentations by ESS staff, identifying the expertise/capacity of permafrost science within ESS, followed by a group discussion on potential collaborative opportunities, new directions, and synergies.

A series of short (approximately eight minutes long) scientific presentations were given, each with about 8 to 12 slides. Presentations were meant to focus on scientific activities geared towards answering specific questions. A key component of the presentations was the identification of gaps, and what was required to improve the work being done. The outline of the presentation structure was as follows:

Slide Number	Title	Purpose
1	Title/ Presenter	Include people involved in activity
2-3	Scientific Background	Overview of the science being conducted (i.e. the question being asked and the science which helps answer it).
4-5	Scientific Application	An explanation of the application of the study (i.e. what is the specific question and how is it being answered), providing more details than the background slide
6-7	Scientific Contribution	An illustration of the scientific accomplishments
8-9	Scientific Activities	A brief description of current activities, collaborators and project partners.
10	Scientific Products	A list of publications
11-12	Scientific Gaps	Identification of gaps in the research and how the work could be improved in the future

Agenda

Time/Location: November 26, 9 – 1:30, Rm 425 615 Booth St.

9:00 9:15 Introductions

Andy Rencz
Dave Scott
Paola de Rose

9:15 10:15 GSC Scientific Presentations

Permafrost Geotechnique for Engineering Design and Land use Planning
Anne-Marie LeBlanc, Wendy Sladen, Sharon Smith and Larry Dyke (Geological Survey of Canada)

Permafrost Modelling in the Mackenzie Valley
C. Duchesne, M. Ednie, F. Wright, M. Côté, and D. Riseborough (Geological Survey of Canada)

Ground Ice Detection and Implications for Permafrost Geomorphology
Nicole Couture and Stephen Wolfe (Geological Survey of Canada)

Characterization of Permafrost and Terrain Conditions for Informed Decision Making Sharon Smith (Geological Survey of Canada)

10:15 10:30 Coffee

10:30 11:30 CCRS Scientific Presentations

Yukon River Basin Ecosystem Performance Anomaly Mapping
Kevin Murnaghan, Brian Brisco (Canada Centre for Remote Sensing), Bruce Wylie, Jennifer Rover, and Norman Bliss (United States Geological Survey)

EO-based Modelling and Mapping of Permafrost
Yu Zhang (Canada Centre for Remote Sensing)

SAR Interferometry for Permafrost Monitoring
Naomi Short, Brian Brisco, Paul Budkewitsch, and Kevin Murnaghan (Canada Centre for Remote Sensing)

11:30 12:30 Discussion

Participants

Scientists

Name	Title	Org.
Couture, Nicole	Permafrost Scientist	GSC-Ottawa
Duchesne, Caroline	Physical Scientist	GSC-Ottawa
Ednie, Mark	Physical Scientist	GSC-Ottawa
LeBlanc, Anne-Marie	Permafrost Geoscientist	GSC-Ottawa
Riseborough, Daniel	Permafrost Scientist	GSC-Ottawa
Sladen, Wendy	Engineering Geomorphologist	GSC-Ottawa
Smith, Sharon	Permafrost Research Scientist	GSC-Ottawa
Wolfe, Stephen	Research Scientist/ Section Head	GSC-Ottawa
Brisco, Brian	Research Scientist	CCRS-Ottawa
Budkewitsch, Paul	Environmental Scientist	CCRS-Ottawa
Chen, Wenjun	Research Scientist	CCRS-Ottawa
Short, Naomi	Environmental Scientist	CCRS-Ottawa
Murnaghan, Kevin	Environmental Scientist	CCRS-Ottawa
Zhang, Yu	Research Scientist	CCRS-Ottawa
Xiping Wang	NSERC Visiting Fellow	CCRS-Ottawa

Management

Name	Title	Org.
de Rose, Paola	Director, EOGD	CCRS-Ottawa
Lysyshyn, Kathleen	Science Planning Advisor	GSC-Ottawa
Rencz, Andy	A/Program Manager	GSC-Ottawa
Scott, David J.	Director, GSC-NC	GSC-Ottawa
Wilkins, Anne	A/Section Head, OMAS	CCRS-Ottawa

Workshop Summary

Introductions

In a brief introduction, Andy Rencz, Program Manager for the Climate Change Geoscience Program, expressed his desire to see stronger collaboration between GSC and CCRS, and hoped that an outcome of this workshop would be new collaborations between these branches of ESS.

Short introductions were made by David Scott, Director of GSC-Northern Division and Paola de Rose, Director of the Earth Observation and Geosolutions Division. These introductions re-iterated an interest in collaboration between these centres of expertise, and emphasized that the North continues to be a priority area for NRCan, particularly with regards to assisting decision-makers and improving the quality of life for Northerners.

Presentations

The workshop consisted of a series of presentations from staff in the Geological Survey of Canada (GSC) and Canada Centre for Remote Sensing (CCRS). They ranged from ground-based scientific experiments, modelling techniques and remote sensing applications in permafrost terrain. The following were included:

GSC Presentations on:

- Permafrost Geotechnical Studies
- Permafrost Modelling in the Mackenzie Valley
- Ground Ice Detection and Implications on Permafrost Geomorphology
- Characterization of Permafrost and Terrain Conditions for Informed Decision Making

CCRS Presentations on:

- Yukon River Basin Ecosystem Performance Anomaly Mapping
- SAR Interferometry for Monitoring Permafrost
- EO-based Modelling and Mapping of Permafrost

Each presentation focussed on the scientific basis for the work, its applications and gaps, followed by questions and discussion. The discussion focused mainly on research gaps so new collaborations and research directions could be established.

Gaps

GSC Presentations:

A main element that ran through most of the GSC presentations was the necessity to have *information scaled to decision-making*. For example from studies in the Mackenzie Valley it was identified that modelling applications and data resolution are not necessarily at the *scale that is needed for policy or planning decision making*. To make sound policy decisions, a modelling scale of about 1 km^2 may be suitable, whereas for planning purposes a finer resolution (closer to 30 m) is required.

Areas in particular that are needed to improve thermal and physical modelling include better data on *vegetation classification* for tundra regions, up to date *forest fire distribution*, *snow cover* at various scales, *soil moisture* and *ground ice* information (at a local scale), *surface organic layer*, including thickness and thermal properties, and *ground disturbance distribution* (landslides and subsidence).

With regard to permafrost geotechnique, it is recognized that parameters such as snow cover thickness and vegetation cover type affect the thermal and physical regime of permafrost but useful datasets are hard to find. The use of both geophysical and remote sensing techniques could be applied to better generate this information (i.e. regional or local scale snow thickness maps). There is a need to be able to *interpolate point information in space and time* to better qualify/quantify the permafrost sensitivity and characteristics (i.e. ground ice content) at a *local scale*. Included in this is slope movement, with regards to changes in elevation and horizontal surface velocities, and temporal variability, with regards to surface conditions and permafrost properties. Also, there is a need to better characterize *warm permafrost* (i.e. permafrost only a degree or two below 0°C) and its mechanical properties as temperatures approach 0°C. In regards to ground ice detection and its implications for permafrost geomorphology, better *ground truthing* for integrated geophysical methods is required, along with better information on the response of ground ice to coastal processes.

With regard to characterization of permafrost and terrain conditions for informed decision making, while the national permafrost monitoring network provides good coverage of many terrain types and conditions, there remain large areas in the Canadian North that require more *information on permafrost thermal conditions*. There are significant areas in the Canadian Arctic, such as in potential mineral resource development areas and across Nunavut, where little information on permafrost thermal conditions or sufficient information on subsurface conditions, such as ice content, exist to adequately characterize terrain sensitivity. In addition, there is a need to *better understand the interaction of processes in dynamic environments* (such as the Mackenzie Delta region) and to better attribute causes of environmental change (such as due to climate change, erosion, or anthropogenic development).

Finally, an improved understanding of *feedbacks* associated with changes in the biophysical environments that accompany changes in permafrost conditions is needed. This is necessary in order to reduce uncertainties in the prediction of future conditions that might change ice/water contents and interactions between hydrology, vegetation and the ground thermal regime (discontinuous permafrost). Remote sensing, with its large area coverage, historical data sets and frequent and reliable revisit periods may be able to contribute to this.

CCRS Presentations:

The CCRS presentations demonstrated terrain and biophysical parameter modelling and measurements derived from remote sensing data. A common theme of the presentations was the need for *ground truth and field validation/calibration of the remote sensing results*. Ideally, ground truth should include field validation representative of the *time of observation*, and with *on-going monitoring*.

For remotely-sensed permafrost modelling and mapping research, *in-situ observations* including *ground temperature, vegetation, snow, and water dynamics*, are needed. In addition, more *detailed soil, geological and hydrological datasets* are required. There is recognition that impacts of permafrost thaw will create *feedbacks* with hydrology, ecosystems, soil organic carbon, and climate, and that these are not generally addressed by the model.

With regard to applications such as SAR interferometry for monitoring permafrost, a *broader suite of sites*, including areas of *discontinuous permafrost*, would be advantageous. In addition, *field experiments* would be required to determine how deep the SAR penetrates the ground, and to what exactly is being measured. The SAR tool and the methodology development is ongoing, but there needs to be *collaboration with field-based geoscience experts* to determine when and where the technique works and under what conditions and *to better parameterize the results*. There is potential that the SMAP satellite (Soil Moisture Active Passive Radar) could be a data source for resolving some questions, however that technology will not be ready until 2014.

With regard to the application of NDVI to model the biophysical environment in permafrost areas (in the presentation case, the Yukon River Basin) it is recognized that the technique was developed for closed canopy ecosystems. Thus, its use in arctic environments requires further refinement.

Synergies

Based on the identified gaps in the presentations and subsequent discussions, potential synergies appeared most likely to occur around issues pertaining to soil moisture, hydrology, land cover, and snow cover, as it applies to permafrost and its sensitivity to changing conditions. In this regard, the issue of scale is paramount, as a working level on the scale of 10s of metres is what is most needed for decision making. Other ongoing remote sensing initiatives that may eventually deliver products useful for permafrost monitoring are SAR utilities for mapping and monitoring surface water and coastal remote sensing projects (e.g. shoreline delineation).

It was recognized that potential opportunities for collaboration can occur where both branches are involved with the same outside partners. In these cases there is potential for both GSC and CCRS expertise to play a role. An example is work with Parks Canada Agency (PCA), where partnership with PCA has the potential for both Earth Observation (EO) based indicators that could work in conjunction with established permafrost monitoring sites (for example, Wapusk National Park). Other partnerships might be established around work with the Canadian Space Agency through the GRIP program or the MORSE initiative.

Future Efforts

Future efforts between GSC and CCRS were summarized briefly, with regards to potential collaboration. In the short term, it was recommended that potential land-based verification/calibration of remote sensing tools be performed using in-situ data gathered by GSC scientists. In the longer term, it is recommended that more pro-active collaboration on activities be considered. Specific areas of collaboration are likely those where data are required with regards to land cover, soil moisture, snow cover and hydrology, and ground surface change.

Abstracts:

Permafrost Geotechnique for Engineering Design and Land Use Planning

Anne-Marie LeBlanc, Wendy Sladen, Sharon Smith and Larry Dyke
(Geological Survey of Canada)

The vulnerability of infrastructure to permafrost degradation strongly depends on the physical, chemical, mechanical and thermal properties of the ground. The study of permafrost properties is essential to understanding how the ground will react to anthropogenic and climatic changes. This knowledge forms the baseline for permafrost geotechnique and its application provides answers to questions involving freezing and thawing processes such as slope movement, frost heave and thaw settlement.

Permafrost geotechnique often uses field investigations to acquire specific knowledge on permafrost conditions. Among them, shallow and deep boreholes are the most common method. Physical, chemical and mechanical properties such as ice and water content, grain size, salinity, and creep parameters are determined from core samples. Boreholes can be used for monitoring ground temperature, hydraulic properties and slope movements by installing thermistor cables, piezometers and inclinometers, respectively. Geophysical methods, which use the electrical (e.g. resistivity or conductivity), electromagnetic (e.g. ground penetrating radar) and seismic properties of the ground, are useful to delineate frozen and unfrozen areas; in addition they provide an alternative tool to measure select physical and mechanical properties such as ice and unfrozen water content, and the Young's and Shear moduli. Finally, in-situ testing tools such as time domain reflectometry antenna, thermal conductivity probe and calorimetric testing provide information on physical and thermal properties while mechanical properties such as creep parameters are measured with pressuremeter and cone penetration test.

Increased infrastructure in the north linked to development of natural resources and population growth emphasizes the need to incorporate permafrost sensitivity into engineering design and land use planning. Experience with the Norman Wells pipeline has highlighted the need to understand the pipeline distress that has occurred due to slow but ongoing creep deformation. Through field instrumentation and geophysical surveys, the GSC has been documenting the mechanical behaviour of frozen and thawing slopes. At a community level, land use planners have to deal with a broad range of terrain instability, which may be amplified by climate change, and that may threaten the integrity of current and future infrastructure. Using the geotechnique investigative methods, processes involved in permafrost degradation such as thaw settlement or thermal erosion are studied to assess permafrost sensitivity at the community scale. As an example of contribution, the integration of different layers of geotechnical and geophysical information has been use to build a 3D community-based thermal model for climate change impact assessment. A similar kind of methodology or tool for land management and decision making is currently being developed at the GSC through the Nunavut Landscape Hazard Mapping project. This tool incorporates into a GIS a variety of data layers including digital elevation models (DEM), surface geology, geotechnical

properties, which are interpreted in terms of the permafrost sensitivity and the vulnerability of infrastructure to climate change. This research is currently being conducted in the communities of Pangnirtung and Clyde River, NU. The work is being conducted in partnership with GSC-Calgary (Dr. Rod Smith) and in collaboration with Université Laval (Centre d'études nordiques), Memorial University, the Canada-Nunavut Geoscience Office and the Government of Nunavut. Hazard risk assessment maps will be produced along with a methodology for conducting similar studies.

Permafrost geotechnique is also being applied in activities conducted in collaboration with Parks Canada. Characterisation of the permafrost conditions at York Factory National Historic Site, northern Manitoba, was completed using similar methods discussed above. At a more regional scale, characterisation of the permafrost sensitivity with respect to different wetland types is being carried out in Wapusk National Park, MB. Parks Canada incorporates the results of these two projects in the development of their management plans.

In general, permafrost geotechnique investigations are often restricted to point locations and a limited time frame. Some of the main challenges are to 1) interpolate between known data locations, 2) extrapolate this knowledge over a larger area, and 3) assessing the temporal variability in permafrost conditions. Because of the influence of surface characteristics (i.e. snow and vegetation cover) on permafrost conditions, there is the potential that high resolution satellite imagery could aid in overcoming some of these challenges.

Publications

LeBlanc**, A.-M.,** Fortier, R., Allard, M., Therrien, R. 2008. The influence of snowdrift on the geothermal field of permafrost: Result from three-dimensional numerical simulations at a local scale (Extented abstract and poster). Ninth International Permafrost Conference, Fairbanks, Alaska, June 29 – July 3 2008 : 171-172.

Fortier, R., LeBlanc, A.-M., Buteau, S., Allard, M., Calmels, F.C. 2008. Internal structure and conditions of permafrost mounds at Umiujaq in Nunavik, Canada, inferred from field investigation and electrical resistivity tomography. Canadian Journal of Earth Sciences, 45(3): 367-387.

LeBlanc, A.-M., Fortier, R., Cosma, C.G. & Allard, M. 2006. Tomography imaging of permafrost using three-component seismic cone penetration test. Geophysics, 71(5), H55-H65.

LeBlanc, A.-M., Fortier, R., Allard, M. & Cosma, C.G. 2004. Seismic cone penetration test and seismic tomography in permafrost. Canadian Geotechnical Journal, 41(5): 796-813.

Fortier, R., Allard, M., Gagnon, O., LeBlanc, A.-M**.** 2004. Assessment of permafrost conditions at Salluit, Nunavik, using cone penetration tests. Proceedings of 57th Canadian Geotechnical Conference. Québec, Canada: 39-47.

Permafrost Modelling in the Mackenzie Valley

Caroline Duchesne, Mark Ednie, Fred Wright, Michelle Côté, and Dan Riseborough (Geological Survey of Canada)

The actual distribution and character of permafrost across Canada is poorly understood and in most cases is represented by the highly generalized Permafrost Map of Canada which describes only broad zones of continuous, discontinuous, or sporadic permafrost. While this map is useful for visualization on a small scale (eg 1:7 000 000), it is inadequate for addressing climate change issues because it contains no information about the actual distribution of frozen vs. unfrozen ground, probable ranges of ground temperature, or local/regional variations in permafrost thickness. Modeling at small scale (1 km resolution) may be suitable for policy development, but intermediate scale modeling (30 m resolution) is more appropriate for planning purposes. High-resolution information about permafrost and associated geotechnical characteristics is required by engineers, regulators, and community stakeholders responsible for assessing potential risks to infrastructure and traditional northern lifestyles in the face of climate change.

The Geological Survey of Canada has developed transient numerical modeling to help estimate the current distribution and thickness of frozen ground in the Mackenzie River valley and to generate time-series predictions of future impacts to permafrost under a progressively warming climate. A one-dimensional finite element heat conduction model (T-ONE), integrated into an ArcGIS spatial analysis platform, enables pseudo 3-dimensional modeling of ground thermal conditions across extensive geographic areas. Ground and surface temperatures from instrumented boreholes and active layer measurements were used to calibrate the model and validate outputs. The model is physically-based, incorporating key climate and terrain factors considered to exert significant influence on the ground thermal state.

Current permafrost characteristics as well as predictions of possible impacts of climate change are necessary for engineers and decision-makers who are responsible for the maintenance and planning of infrastructure projects. This model was used to predict current ground thermal conditions and permafrost characteristics along NWT highways and roads, and potential climate-induced changes to permafrost that may be realized over practical engineering time frames. These predictions were used to identify areas within the transportation corridors that would have significantly greater thaw depths leading to possible subsidence and terrain instability.

The application of transient numerical modeling to geo-statistical methods can be used to generate secondary knowledge products. Using a Weight-of-Evidence based landscape-process model, multiple terrain factors such as geology, permafrost, topography/topology and surface hydrology are used to identify and map terrain susceptibility to various types of terrain instability, including retrogressive thaw flows and rotational slides. For the T-ONE transient results, limited ground truthing and statistical validation of modeling outputs have established a reasonable level of confidence in model performance within the broader Mackenzie Valley. Several data and knowledge gaps remain, such as surface organic layer thickness and properties, snow cover, up to date forest fire distribution, as well as location and persistence of air temperature inversions. Also, the correlation between geomorphologic units and moisture/ice content is mostly based on expert knowledge. A more rigorous approach to quantify the amount and distribution of frozen and unfrozen water at various scales would help resolves some latent heat issues.

Publications

Duchesne, C., J.F. Wright, and M. Ednie (2008) High-Resolution Numerical Modeling of Climate Change Impacts to Permafrost in the Vicinities of Inuvik, Norman Wells, and Fort Simpson, NT, Canada. 9th International Conference on Permafrost, Fairbanks, Alaska, June 29-July 3, 2008.

Ednie, M., J.F. Wright, and C. Duchesne (2008) Establishing Initial Conditions for Transient Ground Thermal Modeling in the Mackenzie Valley: A Paleo-Climatic Reconstruction Approach. 9th International Conference on Permafrost, Fairbanks, Alaska, June 29-July 3, 2008.

Wright, J.F., Duchesne, C. and M.M. Côté. 2003. Regional-scale permafrost mapping using the TTOP ground temperature model, in Proceeding of the 8th International Conference on Permafrost, Zurich, Switzerland, 21 - 25 July 2003.

Ground Ice Detection and Implications for Permafrost Geomorphology

Nicole Couture and Stephen Wolfe
(Geological Survey of Canada)

Most permafrost contains ground ice, often as pore ice or thin veins or lenses of ice. In certain circumstance, larger bodies of ice can form, such as ice wedges, or massive lenses up to tens of metres thick. These ice bodies can be quite pure and, on a volume basis, can occupy up to 97% of the subsurface. The location, type and quantity of this ice are important for several reasons. From a practical perspective, ground ice affects the thermal and physical properties of the ground, and can cause major landscape disturbances upon thawing. In addition, understanding its emplacement helps to explain landscape history. For instance, identifying buried glacier ice can help in explaining the glacial history of a region.

A main objective of our research is to determine the areal and the stratigraphic distribution of ground ice. The goal is to identify where different ice types are likely to occur, and how much ice is present. Note that this is not the same as mapping the distribution of permafrost. Often it is possible to identify the presence of ice by its association with geomorphic features at the surface. For example, the thaw of massive ice can form a retrogressive thaw slump which leaves a distinct crescentic scar. Ice wedges will often have a trough at the surface, forming a polygonal net on the tundra, although these can sometimes be masked by vegetation cover. Pingoes are distinctive ice-cored hills (found mostly in the Mackenzie Delta). A number of other proxies can be used including marine terraces, peat plateaux, or involutions on upland surfaces such as those found near Tuktoyatuk. Subsurface investigations can help detect both the location and the amount of ground ice, either through direct methods such as coring and drilling, or through indirect methods such a geophysics. Surficial geology can also be used, as ground ice is often found in association with specific materials.

When considering the thaw of permafrost, the primary area of concern is often the thawing of the ground ice and how it will be affected by warming at the surface. Thermal modeling is used to assess how quickly a change in surface temperature can propagate to the depth of the ice bodies. The ground thermal properties used in the modeling are often a function of the ground ice content in the upper layers, however, and if they cannot be measured directly, then values are estimated or extrapolated from sites with similar conditions. Also of interest, is how the thaw of ground ice changes the landscape. The most obvious changes are geomorphic – mass movements on slopes, or subsidence of the ground surface proportional to the loss of ice volume. These are the processes which can have serious implications for infrastructure. Knowledge of the geotechnical properties of the sediments is necessary for these types of investigations. Major changes to hydrological regimes are another consequence of ground ice thaw, either because of water accumulation or through the development of new drainage pathways. This, in turn, can affect vegetation. The thermal regime can be affected by water or snow accumulation in thermokarst depressions. Thawing ground ice can also change the geochemistry of water bodies by mobilizing salts, metals, organic carbon and sediment. Therefore, ice and enclosing sediments are typically sampled for geochemical analyses.

Research activities include a project that is part of the Program on Energy Research and Development. It involves mapping the distribution of ice-rich permafrost around Parson's Lake north of Inuvik, at the site of a planned natural gas processing and distribution facility. The site was chosen because geotechnical data are available from a previous drilling program which make it a useful training site for calibrating techniques that combine several geophysical tools : GPR, resistivity, and conductivity. Stratigraphic maps of the subsurface can be produced from these data, providing two types of information: 1) the extent of massive ice bodies, and 2) changes in stratigraphic ice contents. Ice content data are used to parameterize thermal models and estimate how the ground ice will be affected by surface changes. Following calibration, the techniques can be applied to sites with little baseline information is available. This type of approach is also being used to detect ground ice at granular resources sites. The ground ice affects extraction activities because 1) its thaw can disrupt infrastructure, hydrology, etc., and 2) the volume it occupies can lead to an overestimate of the resources that are actually available. This knowledge will assist in developing regulatory policies for development sites.

Another approach we use involves morphological mapping to quantify ground ice volumes at the landscape scale. Stratigraphic relationships between different ice types and the ice contents of each type are examined in order to assess the actual volume of ice in various types of terrain units. This information can then be applied to modelling the geomorphic changes that might be expected at the landscape scale as a result of climate warming, or the volume of material fluxes. The amount of sediment or contaminants is highly dependent on the volume of ground ice. So if ground ice accounts for 30% or 50% or 75% of soil volume, it has a major effect on sediment or contaminant budgets. This has implications for water geochemistry and ecology; it also affects coastal erosion rates, posing a threat to infrastructure, or increasing channel sedimentation and hazards to navigation.

Current activities are centered in the Mackenzie Delta region. The Parson's Lake project, discussed above, is undertaken in conjunction with McGill University, Indian and Northern Affairs Canada (INAC), and industrial partners. Other work has involved mapping of ground ice in coastal areas to estimate organic carbon fluxes along the Yukon coast and collaboration with the GSC Atlantic to assess sediment transport in the Mackenzie Delta during spring break up, as well as the role of ground ice in coastal stability. A related activity involves assisting CCRS to ground truth and interpret their InSAR data, with regards to ground ice on Herschel Island. Ground ice and resulting coastal fluxes are also part of a new project in the Environmental Geoscience Program examining the mobilization of mercury in the Arctic. Others partners in this project are the Arctic Monitoring and Assessment Program (AMAP), INAC's Northern Contaminants program, University of Manitoba, and the Alfred Wegener Institute in Germany.

At the international level, we are involved with the Arctic Coastal Dynamics project and AMAP in investigating fluxes of various sorts from eroding permafrost and developing a better understanding of the role of ground ice in controlling what occurs in the near offshore as well as the onshore zones. In the near future, with plans for an Inuvik-Tuktoyaktuk all-weather road, there will likely be a need for work related to terrain sensitivity of ice-rich terrain, and extraction of granular resources required for the project. In addition, the effect of ground ice on coastal erosion along the Yukon and NWT is of interest to Parks Canada's because of heritage sites that are threatened by erosion.

The use of integrated geophysical methods for assessing ground ice distribution and stratigraphy still requires much ground truthing. The relationship between ground ice and sediment transport in coastal areas needs to be better developed. This is especially important, given the effects of a warming climate, including changing air and water temperatures, rising sea level, increased storminess and decreasing sea ice cover. The MORSE Arctic Coastal Initiative (CSA and ESA sponsored) outlined a number of EO requirements and information needed from a range of users.

Publications

Couture, N.J., Hoque, A.Md., Pollard W.H. (2008) Modelling the erosion of ice-rich deposits along the Yukon Coastal Plain. Ninth International Conference on Permafrost, June 29-July 3, 2008, Fairbanks, Alaska, 303-308.

Overduin, P. P. and Couture, N.J. (eds.) (2008). The 6th annual Arctic Coastal Dynamics (ACD) workshop, Oct. 22-26,2006, Groningen, Netherlands. Berichte zur Polar- und Meeresforschung/ Reports on Polar and Marine Research, 576, 105 pp.

Pollard, W.H. and Couture, N.J. (2008). Massive ground ice in the Eureka Sound Lowlands, Canadian High Arctic. Ninth International Conference on Permafrost, June 29-July 3, 2008, Fairbanks, Alaska, 1433-1438.

Lantuit, H., Overduin, P.P., Couture, N.J., Ødegård, R.S. (2008). Sensitivity of coastal erosion to ground ice contents: An Arctic-wide study based on the ACD classification of Arctic coasts. Ninth International Conference on Permafrost, June 29-July 3, 2008, Fairbanks, Alaska, 1025-1029.

Couture, N.J., and Overduin, P.P. (2008). Monitoring Arctic Coastal Dynamics. Ice and Climate News, No. 11, Aug., Climate and Cryosphere (CliC).

Couture, N.J., and Pollard, W.H. (2007). Modelling geomorphic response to climatic change. Climatic Change, 85: 407-431. DOI 10.1007/s10584-007-9309-5.

Couture, N.J., and Spiridonov, V. (2006). Coastal Changes. Arctic Bulletin, World Wildlife Fund International Arctic Programme, No. 1.06, pp.15-16.

Overduin, P.P. and Couture, N.J. (eds.) (2006). Arctic Coastal Dynamics II – Science and Implementation Plan. Developed at the ACD II workshop, October 22-26, 2006 at the Arctic Centre, University of Groningen, Netherlands, 19 pp.

Rachold, V., Lantuit, H., Couture, N.J., Pollard, W.H., eds. (2005). Arctic Coastal Dynamics: Report of the 5th International Workshop. Berichte zur Polar- und Meeresforschung, 506, 131 pp.

Lantuit, H., Couture, N.J., Pollard, W.H., Haltigin, T., De Pascale, G.P., and Budkewitsch, P. (2005). Short-term evolution of coastal polycyclic retrogressive thaw slumps on Herschel Island, Yukon Territory. Berichte zur Polar- und Meeresforschung, 506, pp. 72-76.

Lantuit, H., Couture, N.J., and Pollard, W.H. (2004). A volumetric analysis of long-term coastal erosion on Herschel Island, Yukon Territory: Preliminary results. Berichte zur Polar- und Meeresforschung, 482, pp 33-37.

Pollard, W.H., Omelon, C.R., Couture, N.J., Solomon, S. and Budkewitsch, P. (2002). Ice content and sensitivity analysis based on landscape interpretation for several sites along the Beaufort Sea coast. Berichte zur Polar- und Meeresforschung, 413: 48-52.

Pollard, W.H. and Couture, N.J. (2000). Application of morphological methods to estimation of ground ice content at selected sites along the Beaufort Sea coast. Report for the Geological Survey of Canada (Atlantic), 39 pp.

Couture, N.J. (2000). Sensitivity of permafrost terrain in a high Arctic polar desert: an evaluation of response to disturbance near Eureka, Ellesmere Island, Nunavut. Unpublished M.Sc. thesis, McGill University, Montreal, Quebec, 102 pp.

Pollard, W.H. and Couture, N.J. (1999). The use of morphological methods to estimate ground ice volumes along the Canadian Beaufort Sea coast. Report for the Geological Survey of Canada (Atlantic), 30 pp.

Couture, N.J. and Pollard W.H. (1998). An assessment of ground ice volume near Eureka, Northwest Territories. Permafrost, Seventh International Conference, June 23-27, Yellowknife, Canada. A.G. Lewkowicz and M. Allard (eds.). Université Laval, Centre d'études nordiques, Collection Nordicana, 195-200.

Characterization of Permafrost and Terrain Conditions for Informed Decision Making

Sharon Smith
(Geological Survey of Canada)

Permafrost is an important feature of the Northern Canadian landscape that has impacts on the natural and socio-economic environments. Permafrost and its associated ground ice can influence ecosystems through its influence on drainage patterns and ground stability as well as present challenges to northern development. Permafrost may warm and thaw in response to climate warming or disturbance to the ground surface such as that due to clearance of vegetation associated with development or natural processes such as fire. Thawing of permafrost can lead to landscape instability, thermokarst development and ground subsidence which have important implications for northern infrastructure, hydrological processes, ecosystems and northern lifestyles. Knowledge of permafrost conditions, including thermal state and ground ice conditions, and their spatial and temporal variations is critical for engineering design of infrastructure in northern Canada, the assessment of environmental impacts and the characterization of the impacts of climate change. Ongoing monitoring of permafrost conditions is essential to understand how these conditions may change over time, to assess impacts on natural and human systems, to develop strategies to mitigate these changes and to improve predictions of future conditions.

Utilization of observations of permafrost thermal conditions, soil properties, climatic conditions and other environmental parameters along with analysis and modeling techniques has facilitated an improved characterization and explanation of the spatial variation in permafrost conditions across the Canadian north and quantification of the rate of increase in permafrost temperatures over the past two to three decades. A key achievement has been the enhancement of the permafrost thermal monitoring network to provide information for areas where little recent information was available. An improved baseline is now available against which change can be measured. This is essential for environmental management programs associated with northern development as a baseline is required against which project impacts can be calibrated.

A major regional component is the Mackenzie Valley where key baseline and science gaps related to proposed hydrocarbon development are being addressed. Analysis of data collected through permafrost and terrain monitoring over the last 25 years along the existing Norman Wells to Zama pipeline corridor has been utilized to assess the impacts of pipeline construction and operation on the permafrost environment including characterization of changes in thaw depth and associated surface settlement. Integration of modeling techniques to investigate the source of the observed changes in the ground thermal regime have led to a better understanding of the relative influence of climate change and environmental disturbance. These results can be utilized to improve the assessment of environmental impacts and provide guidance for development of environmental monitoring and management programs for development projects. Knowledge has been generated that has informed decisions, environmental management and engineering design, including most notably a transfer of research results to the regulatory-environmental assessment process for the Mackenzie Gas Project. Research results have also been an important contribution to national and international climate change assessments. However, a number of knowledge gaps still exist. Significant areas (e.g. potential mineral resource development areas, arctic communities) still exist where there is insufficient information on permafrost thermal state and subsurface conditions to adequately characterize terrain sensitivity. An improved understanding of the interaction of processes in dynamic environments (e.g. Mackenzie Delta) is required to better attribute causes of environmental change. Improved understanding of feedbacks associated with changes in biophysical environment that accompany changes in permafrost conditions are required in order to reduce uncertainty in prediction of future conditions.

Relevant Publications, last 5 years
Peer Reviewed publications (journal, conference proceedings etc.)

Smith, S.L., and Riseborough, D.W., 2010, Modelling the thermal response of permafrost terrain to right-of-way disturbance and climate warming: Cold Regions Science and Technology. v. 60, p. 62-103, doi: 10.1016/j.coldregions.2009.08.009.

Smith, S.L., Wolfe, S.A., Riseborough, D.W., and Nixon, F.M., 2009, Active-layer characteristics and summer climatic indices, Mackenzie Valley, Northwest Territories, Canada: Permafrost and Periglacial Processes, v. 20, p. 201-220.

Prowse, T.D., Furgal, C., Melling, H., and Smith, S.L., 2009, Implications of climate change for Northern Canada: the physical environment.: Ambio, v. 38, p. 266-271.

Prowse, T.D., Furgal, C., Chouinard, R., Melling, H., Milburn, D., and Smith, S.L., 2009, Implications of climate change for economic development in Northern Canada: energy, resource, and transportation sectors Ambio, v. 38, p. 272-281.

Nguyen, T.-N., Burn, C.R., King, D.J., and Smith, S.L., 2009, Estimating the extent of near-surface permafrost using remote sensing, Mackenzie Delta, Northwest Territories: Permafrost and Periglacial Processes, v. 20, p. 141-153.

Kokelj, S.V., Lantz, T.C., Kanigan, J., Smith, S.L., and Coutts, R., 2009, Origin and polycyclic behaviour of tundra thaw slumps, Mackenzie Delta region, Northwest Territories, Canada: Permafrost and Periglacial Processes, v. 20, p. 173-184.

Smith, S.L., Burgess, M.M., and Riseborough, D.W., 2008, Ground temperature and thaw settlement in frozen peatlands along the Norman Wells pipeline corridor, NWT Canada: 22 years of monitoring., in Kane, D.L., and Hinkel, K.M., eds., Ninth International Conference on Permafrost, Volume 2: Fairbanks Alaska, Institute of Northern Engineering, University of Alaska Fairbanks, p. 1665-1670.

Parsons, M.A., Smith, S.L., Romanovsky, V.E., Shiklomanov, N.I., Christiansen, H.H., Overduin, P.P., Zhang, T., Balks, M.R., and Brown, J. 2008. Managing Permafrost Data: past approaches and future directions. In Ninth International Conference on Permafrost. Edited by D.L. Kane and K.M. Hinkel. Fairbanks, Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, Vol.2, pp. 1369-1374.

Woo, M.-k., Molligna, M., and Smith, S.L., 2008, Modeling maximum active layer thaw in boreal and tundra environments using limited data, in Woo, M.-k., ed., Cold Region

Atmospheric and Hydrologic Studies. The Mackenzie GEWEX Experience, Volume 2: Hydrologic Processes: Berlin Heidlelberg, Bringer-Verlag, p. 125-137.

Woo, M.-k., Mollinga, M., and Smith, S.L., 2007, Climate warming and active layer thaw in the boreal and tundra environments of the Mackenzie Valley: Canadian Journal Earth Science, v. 44, p. 733-743.

Woo, M.-k., Mollinga, M., and Smith, S.L., 2006, Simulating active layer thaw in a boreal environment: Géographie Physique et Quaternaire, v. 60, p. 9-17.

Woo, M.-K., Mollinga, M. and Smith, S.L. 2006. Modelling maximum active layer thaw in boreal and tundra environments using limited data. Final Report of the Mackenzie GEWEX Study (MAGS); Proceedings of the final (11th) Annual Scientific meeting (Nov. 2005), P. di Cenzo editor, p. 663-672.

Taylor, A.E., Wang, K., Smith, S.L., Burgess, M.M., and Judge, A.S., 2006, Canadian Arctic Permafrost Observatories: detecting contemporary climate change through inversion of subsurface temperature time-series: Journal of Geophysical Research, v. 111.

Atkinson, D.E., Brown, R., Alt, B., Agnew, T., Bourgeois, J., Burgess, M., Duguay, C., Henry, G., Jeffers, S., Koerner, R., Lewkowicz, A.G., McCourt, S., Melling, H., Sharp, M., Smith, S., Walker, A., Wilson, K., Wolfe, S., Woo, M.-k., and Young, K., 2006, Canadian cryospheric response to an anomalous warm summer: a synthesis of the Climate Change Action Fund Project "The state of the Arctic Cryosphere during the extreme warm summer of 1998": Atmosphere-Ocean, v. 44, p. 347-375.

Smith, S.L., Burgess, M.M., Riseborough, D., and Nixon, F.M., 2005, Recent trends from Canadian permafrost thermal monitoring network sites: Permafrost and Periglacial Processes v. 16, p. 19-30.

Smith, S.L., and Burgess, M.M., 2004, Sensitivity of permafrost to climate warming in Canada, Geological Survey of Canada Bulletin 579, 24 p.

Contributions to national and international assessments (all peer reviewed): National

Furgal, C., Prowse, T.D., Bonsal, B., Chouinard, R., Dickson, C., Edwards, T., Jackson, F., Melling, H., Milburn, D., Nickels, S., Nuttall, M., Ogden, A., Peters, D., Reist, J.D., Smith, S., Westlake, M., and Wrona, F., 2008, Northern Canada, in Lemmen, D.S., Warren, F.J., Lacroix, J., and Bush, E., eds., From Impacts to Adaptation: Canada in a changing climate 2007: Ottawa, Government of Canada, p. 57-118.

Brown, R.D., Demuth, M.N., Goodison, B.E., Marsh, P., Prowse, T.D., Smith, S.L., and Woo, M.-K., 2004, Climate Variability & Change - Cryosphere. Chapter 14 in Threats to Water Availability in Canada; NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1, National Water Research Institute, Meteorological Service of Canada, Environment Canada, p. p. 107-116.

Smith, S. in press. Trends in permafrost conditions and ecology in northern Canada. Ecosystem Status and Trends Report for Canada: Thematic Technical Report Series, No. 1. Publisher: Canadian Councils of Resource Ministers, Ottawa.

International

Callaghan, T.V., Johansson, M., Anisimov, O., Christensen, H.H., Instanses, A., Romanovsky, V., Smith, S. in prep. Chapter 5.2 Changing permafrost characteristics, distribution and extent, and their impacts. In Snow Water Ice and Permafrost in the Arctic (SWIPA, Arctic Council project on Cryosphere and Climate)

Romanovsky, V.E., Gruber, S., Instanes, A., Jin, H., Marchenko, S.S., Smith, S.L., Trombotto, D., and Walter, K.M., 2007, Frozen Ground, Chapter 7, in Eamer, J., ed., UNEP Global Outlook for Ice & Snow, United Nations Environment Program, p. 181-200.

Smith also contributing author to WG1 4th IPCC Assessment: Lemke, P., Ren, J., Alley, R.B., Allison, I., Carrasco, J., Flato, G., Fujii, Y, Kaser, G., Mote, P., Thomas, R.H. and Zhang, T. 2007. Chapter 4, Observations: changes in snow, ice and frozen ground. In Climate Change 2007: The Physical Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, p. 337-383.

Geological Survey of Canada publications and database products

Smith, S.L., Nguyen, T.-N., Riseborough, D.W., Ednie, M., Ye, S., and Chartrand, J. 2010 (in press). Baseline geotechnical and permafrost data from new field sites established in the Mackenzie Corridor south of Norman Wells, Northwest Territories. Geological Survey of Canada Current Research 2010-2

Smith, S.L., Riseborough, D.W., Nixon, F.M., Chartrand, J. Duchesne, C. and Ednie, M. 2009. Data for Geological Survey of Canada Active Layer Monitoring Sites in the Mackenzie Valley, N.W.T. Geological Survey of Canada Open File 6287.

Sladen, W., Dyke, L.D., and Smith, S.L., 2009, Permafrost at York Factory National Historic Site of Canada, Manitoba, Canada: Geological Survey of Canada Current Research, v. 2009-4, p. 10.

Smith, S.L., Chartrand, J., Nguyen, T.N., Riseborough, D.W., Ednie, M., and Ye, S., 2009, Geotechnical database and descriptions of permafrost monitoring sites established 2006-07 in the central and southern Mackenzie Corridor, Geological Survey of Canada Open File 6041.

Smith, S.L., Nguyen, T.-N., Riseborough, D.W., Ednie, M., Ye, S., and Chartrand, J., 2008, Preliminary ground-thermal data for permafrost-monitoring sites established in 2007 between Fort Good Hope and Norman Wells, Northwest Territories: Geological Survey of Canada Current Research, v. 2008-20, 9 p.

Smith, S.L., Burgess, M.M., Riseborough, D., and Chartrand, J., 2008, Permafrost and terrain research and monitoring sites of the Norman Wells to Zama pipeline – Thermal data collection and case histories, April 1985 to September 2001, Geological Survey of Canada Open File 5331.

Smith, S.L., Ye, S., and Ednie, M., 2007, Enhancement of permafrost monitoring network and collection of baseline environmental data between Fort Good Hope and Norman Wells, Northwest Territories: Geological Survey of Canada Current Research, v. 2007-B7, 10 p.

Smith, S.L., Burgess, M.M., Chartrand, J., and Lawrence, D.E., 2005, Digital borehole geotechnical database for the Mackenzie Valley/Delta region, Geological Survey of Canada Open File 4924.

Smith, S.L., Burgess, M.M., Riseborough, D., Coultish, T., and Chartrand, J., 2004, Digital Summary Database of Permafrost and Thermal Conditions – Norman Wells Pipeline Study Sites, Geological Survey of Canada Open File 4635.

Published extended abstracts in Conference Proceedings

James, M., Lewkowicz, A.G., Smith, S.L., and Lipovsky, P. 2008. Historic change in permafrost distribution in northern British Columbia and southern Yukon. In Ninth International Conference on Permafrost, Extended Abstracts. Edited by D.L. Kane and K.M. Hinkel. Fairbanks Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, pp. 115-116.

Nguyen, T.-N., Burn, C.R., King, D.J., and Smith, S.L. 2008. Estimation of the extent of near-surface permafrost in the Mackenzie Delta, Northwest Territories, using remote sensing. In Ninth International Conference on Permafrost, Extended Abstracts. Edited by D.L. Kane and K.M. Hinkel. Fairbanks Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, pp. 221-222.

Smith, S.L., Lewkowicz, A.G., and Burn, C.R. 2008. Thermal state of permafrost in Canada: a contribution to the International Polar Year. In Ninth International Conference on Permafrost, Extended Abstracts. Edited by D.L. Kane and K.M. Hinkel. Fairbanks Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, pp. 295-296.

Throop, J.L., Smith, S.L., and Lewkowicz, A.G. 2008. Effect of a snow fence on the shallow ground thermal regime, Baker Lake, Nunavut, Canada. In Ninth International Conference on Permafrost, Extended Abstracts. Edited by D.L. Kane and K.M. Hinkel. Fairbanks Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, pp. 313-314.

Smith, S.L., Burgess, M.M., Romanovsky, V., Clow, G.D., Nelson, F.E. and Brown, J. 2004. Global Terrestrial Network for Permafrost (GTN-P) - A contribution to improved understanding of the Arctic climate system. Session B7: Paper 6, (extended abstract) Arctic Climate Impact Assessment International Symposium on Climate Change in the Arctic Reykjavik, Iceland, November 2004. AMAP Report 2004:4

Yukon River Basin Ecosystem Performance Anomaly Mapping

Kevin Murnaghan, Brian Brisco (Canada Centre for Remote Sensing),
Bruce Wylie, Jennifer Rover, Norman Bliss (United States Geological Survey)

The Yukon River Basin (YRB) is contained in Alaska, Yukon Territory and British Columbia. Under Annex 17 of the MOU between NRCan/CCRS and USGS/EROS annual maps of ecosystem performance anomalies were produced.

Growing season average Normalized Difference Vegetation Index (NDVI) was produced from MODIS with 250 m resolution for years 2000-2005 and used as a proxy for ecosystem performance. A regression tree model for site potential was generated using permafrost (Ice Content, Extent and Landform), surface geology, elevation, slope/aspect, Compound Topographic Index (CTI), ecoregions, clusters, solar radiation, and Annual Moisture Index (AMI). A performance model included the site potential model and weather data including maximum temperature, minimum temperature, precipitation, and growing degree days for four periods each year. The predominant land cover type, boreal forest, was used, and excluded areas burnt in the previous 30 years. The model was trained using over 15,000 points from different years and different productivities. The residual between measured performance and the modelled performance was calculated. The top 10% was classified as over performing and the bottom 10% was classified as underperforming. An anomaly map was generated for each year of the study. Comparison of forest fire perimeters and detected anomalies show good correspondence. Further work is required to identify the cause of additional anomalies. Possible other causes include insect infestation, land cover change, or changes to drainage conditions from permafrost degradation. The annual anomaly maps were analyzed to find persistent or emerging over and under performance areas.

Publications

Wylie, B.K., Zhang, L., Bliss, N.B., Ji, L., Tieszen, L.L., and Jolly, W.M., 2008, Integrating modeling and remote sensing to identify ecosystem performance anomalies in the boreal forest, Yukon River Basin, Alaska. International Journal of Digital Earth, 1: 196-220.

Wylie, B.K., K. Murnaghan, L. Zhang, J. Rover, L. Ji, B. Brisco, L.L. Tieszen, 2008, Satellite based monitoring of climate effects and disturbances in the boreal forests of the Yukon River Basin, Park Science in the Arctic - Natural and Cultural Heritage of Greater Beringia: the 2008 Alaska Park Science Symposium,

Wylie, B.K., Murnaghan, K., Rover, J. A., Tieszen, L. L., Brisco, B, 2009, Modeling boreal forest performance with MODIS, site characteristics, and weather to monitor climate, management, and disturbance impacts. AGU Fall 2009 Meeting Poster.

Brisco, B., N. Short, P. Budkewitsch, K. Murnaghan and F. Charbonneau, 2009, SAR Interferometry and Polarimetry for Mapping and Monitoring Permafrost in Canada, POLinSAR 2009, the 4th International Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry, ESRIN, Frascati, Italy, 26-30 January.

EO-based Modelling and Mapping of Permafrost

Yu Zhang (Canada Centre for Remote Sensing)

Observations have shown that climate is warming, and permafrost is thawing. The major questions now facing us are what are its impacts and consequences, and what can we can do about it. To answer these questions, we need to know more details about permafrost thaw, such as how permafrost will thaw, where, when, and how much. Field observations are essential, but they have limitations in spatial and temporal coverages. Satellite remote sensing (or Earth Observation, EO) can provide detailed spatial information about land surface, and process-based models are important tools for data synthesizing, process understanding, and future projections. EO-based modelling combines these two technologies and can provide spatial distributions and changes based on observations and our understanding. Following this approach, we developed a process-based permafrost model considering the impacts of climate, vegetation, snow, water, soil features and geological conditions. With the inputs of atmospheric climate, vegetation and ground surface conditions from remote sensing, and soil and geological data, we can model ground temperature profiles, active-layer thickness, permafrost conditions, and their spatial distributions and changes with time. We conducted a nation-wide permafrost modelling and mapping study for Canada. The model simulated ground temperature, permafrost distribution, active-layer thickness, and permafrost depth are comparable with observations. The results show that the area underlain by permafrost in Canada will be reduced by 16-20% from the 1990s to the 2090s, and permafrost degradation will continue after the 21st century because the ground thermal regime is in disequilibrium. Now we are working with Parks Canada Agency to model and map permafrost in some northern national parks at a higher spatial resolution. This collaboration not only serves Parks Canada Agency for their monitoring and management operations, but it also provides us a reliable and cost-effective test bed for our methods and results. This EO-based permafrost modelling and mapping work has been supported by the climate change program in ESS, a GRIP project, ParkSpace, funded by Canadian Space Agency, and a IPY project, CiCAT.

Publications

Zhang, Y., W. Chen, and D.W. Riseborough. Disequilibrium Response of Permafrost Thaw to Climate Warming in Canada over 1850-2100, *Geophysical Research Letters,* 35, L02502, doi:10.1029/2007GL032117, 2008.

Zhang, Y., W. Chen, and D.W. Riseborough. Transient projections of permafrost distribution in Canada during the 21st century under scenarios of climate change. *Global and Planetary Change,* 60: 443-456, doi:10.1016/j.gloplacha.2007.05.003, 2008.

Zhang, Y., W. Chen, and D.W. Riseborough, Modeling the long-term dynamics of snow and their impacts on permafrost in Canada. In: Kane, D.L. and K.M. Hinkel (eds), *Ninth International Conference on Permafrost*, Institute of Northern Engineering, University of Alaska Fairbanks, p2055-2060, 2008.

Zhang, Y., W. Chen, and D.W. Riseborough. Temporal and spatial changes of permafrost in Canada since the end of the Little Ice Age. *Journal of Geophysical Research* 111, D22103, doi:10.1029/2006JD007284, 2006.

Zhang, Y., W. Chen, S.L. Smith, D.W. Riseborough, and J. Cihlar. Soil temperature in Canada during the 20th century: complex responses to atmospheric climate change. *Journal of Geophysical Research,* 110, D03112, doi:10.1029/2004JD004910, 2005.

Chen, W., Y. Zhang, J. Cihlar, S.L. Smith, and D.W. Riseborough. Changes in soil temperature and active-layer thickness during the 20th century in a region in western Canada. *Journal of Geophysical Research, 108*(D22), 4696, doi:10.1029/2002JD003355. 2003.

Zhang, Y., W. Chen, and J. Cihlar. A process-based model for quantifying the impact of climate change on permafrost thermal regimes. *Journal of Geophysical Research, 108*(D22), 4695, doi:10.1029/2002JD003354, 2003.

Zhang, Y., C. Li., C.C. Trettin, H. Li, and G. Sun. An integrated model of soil, hydrology and vegetation for carbon dynamics in wetland ecosystems. *Global Biogeochemical Cycles,* Vol. 16, No. 4, 1061, doi:10.1029/2001GB001838. 2002.

SAR Interferometry for Permafrost Monitoring

Naomi Short, Brian Brisco, Paul Budkewitsch, Kevin Murnaghan
(Canada Centre for Remote Sensing)

Synthetic Aperture Radar interferometry (InSAR) is a technique that can be used to measure ground movement from two or more SAR acquisitions. The SAR data sets must be of the same area, acquired with exactly the same radar properties and the same viewing geometry, and separated by a period of time. When the SAR data are processed carefully and controlled for errors, the resulting patterns of phase shift can be converted to patterns of ground movement.

While the theory of InSAR for permafrost environments is well established, SAR satellite limitations have made it difficult, if not impossible, to carry out regular monitoring. In the past four years three new SAR satellites have been launched with dramatically improved capabilities for InSAR. These sensors are ALOS-PALSAR (L-band SAR), RADARSAT-2 (C-band SAR) and TerraSAR-X (X-band SAR).The project at CCRS is a comprehensive exploration of these new sensors and their capabilities for use in permafrost environments.

Preliminary results show that the quality of the InSAR data pairs from the new sensors is very high and that ground movement patterns can be clearly identified. Figure 1 shows the ground displacement detected over Herschel Island between August 19 and October 4, 2007, using ALOS-PALSAR data. Significant subsidence is observed on the north coast and over the higher elevation areas.

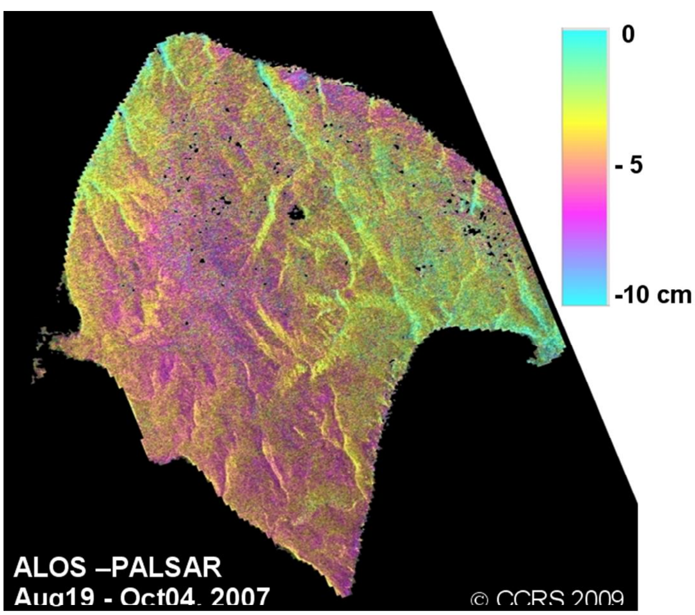

Figure 1. Ground displacement between August 19 and October 4, 2007, from ALOS-PALSAR interferometry.

Figure 2. shows the ground displacement detected over a one year period for the same area, also using ALOS-PALSAR data. Again significant subsidence is noted along

the north coast. Other subsidence patterns seem more related to surface hydrology and breaks in surface slope.

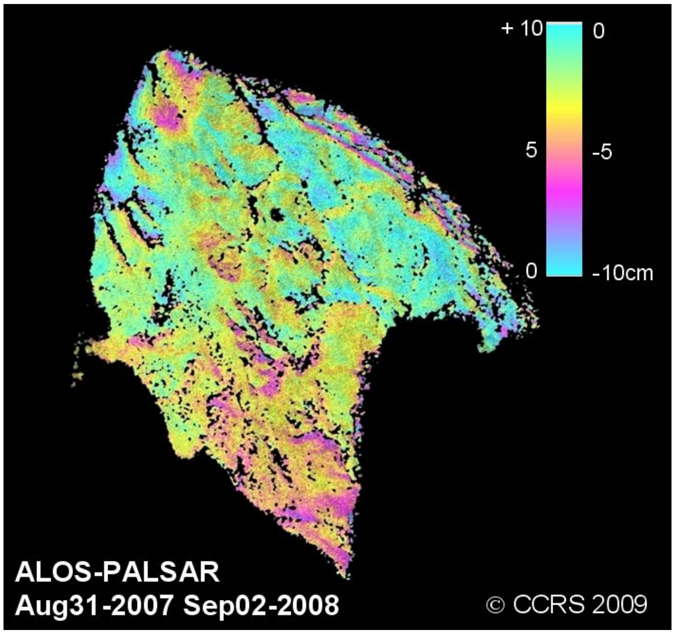

Figure 2. Ground displacement between August 31, 2007 and September 2, 2008, from ALOS-PALSAR interferometry.

The SAR sensors recently launched appear to hold significant promise for detecting ground displacement patterns over larger areas than are possible with ground surveys. Both seasonal and longer term trends can be detected. Future work includes plans for field validation and investigation of the high resolution modes of RADARSAT-2 and TerraSAR-X.

Publications

Short, N., B. Brisco, L. Gray, P. Budkewitsch, and K. Murnaghan (2008). ALOS InSAR for Permafrost Monitoring Applications, Proceedings of ALOS PI 2008 Symposium, November 3-7, 2008, Rhodes, Greece, SP-664, ESA Communication Production Office.

Short, N., B. Brisco, P. Budkewitsch, and K. Murnaghan (2009). ALOS-PALSAR Interferometry for Permafrost Monitoring in Canada. Proceedings of the 3rd ALOS PI Symposium, November 9-13, 2009, Hawaii. Alaska SAR Facility.